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Smoky Canyon Mine

Pilot Study Report

Zero-Valent Iron Treatment Technology – South Fork Sage Creek Springs

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LIST OF ACRONYMS

AOC	Administrative Order on Consent
COPC	Constituents of Potential Concern
DO	Dissolved Oxygen
EECA	Engineering Evaluation/Cost Analysis
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
gpm	gallons per minute
IDEQ	Idaho Department of Environmental Quality
ODA	Overburden Disposal Area
RI	Remedial Investigation
SAP	Sampling and Analysis Plan
SI	Site Investigation
SOW	Statement of Work
TCLP	Toxicity Characteristics Leaching Procedure
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USFS	U.S. Forest Service
ZVI	Zero Valent Iron

1.0 INTRODUCTION

The purpose of this report is to describe the implementation and results of a water treatment pilot study conducted by J.R. Simplot Company (Simplot) using a zero valent iron (ZVI) treatment process developed by Liberty Hydrologic Systems (Liberty). The study was performed at the Smoky Canyon Mine from October 5, 2009 to September 12, 2011.

1.1 Background Information

Simplot owns and operates the Smoky Canyon phosphate mine in southeastern Idaho (Figure 1-1). The Smoky Canyon Mine is the subject of a 2009 Administrative Settlement Agreement/Order on Consent (AOC) entered into by the U.S. Forest Service (USFS), U.S. Environmental Protection Agency (EPA), Idaho Department of Environmental Quality (IDEQ), and Simplot (USFS, 2009). The AOC, and its accompanying Statement of Work (SOW), provides a mechanism to conduct a Remedial Investigation (RI) and Feasibility Study (FS). In accordance with that AOC, Simplot is investigating the potential environmental effects of historical phosphate mining and milling operations at the Smoky Canyon mine to support development of remedies to address any environmental conditions that represent a risk to human health or the environment.

Simplot previously completed a Site Investigation (SI) and draft Engineering Evaluation/Cost Analysis (EECA) at the Smoky Canyon Mine in accordance with an earlier AOC (USFS, 2003). The SI identified elevated selenium concentrations in certain surface waters downstream of the mining-disturbed areas, including lower Pole Canyon Creek, Hoopes Spring, and lower Sage Creek (NewFields, 2005). The primary sources of selenium are Overburden Disposal Areas (ODAs). Elevated concentrations of selenium and other constituents of potential concern (COPCs) were also observed in seeps emanating from ODAs at the mine's D Panel and E Panel. The draft EECA Report was not accepted as complete and final by the USFS, but the USFS did rely on portions of that report to select a source-control interim removal action for the Pole Canyon ODA (USFS, 2006). The Pole Canyon Non-Time Critical Removal Action was selected to reduce selenium transport from the Pole Canyon ODA to Hoopes Spring and to surface water. Removal Action construction was completed in 2008.

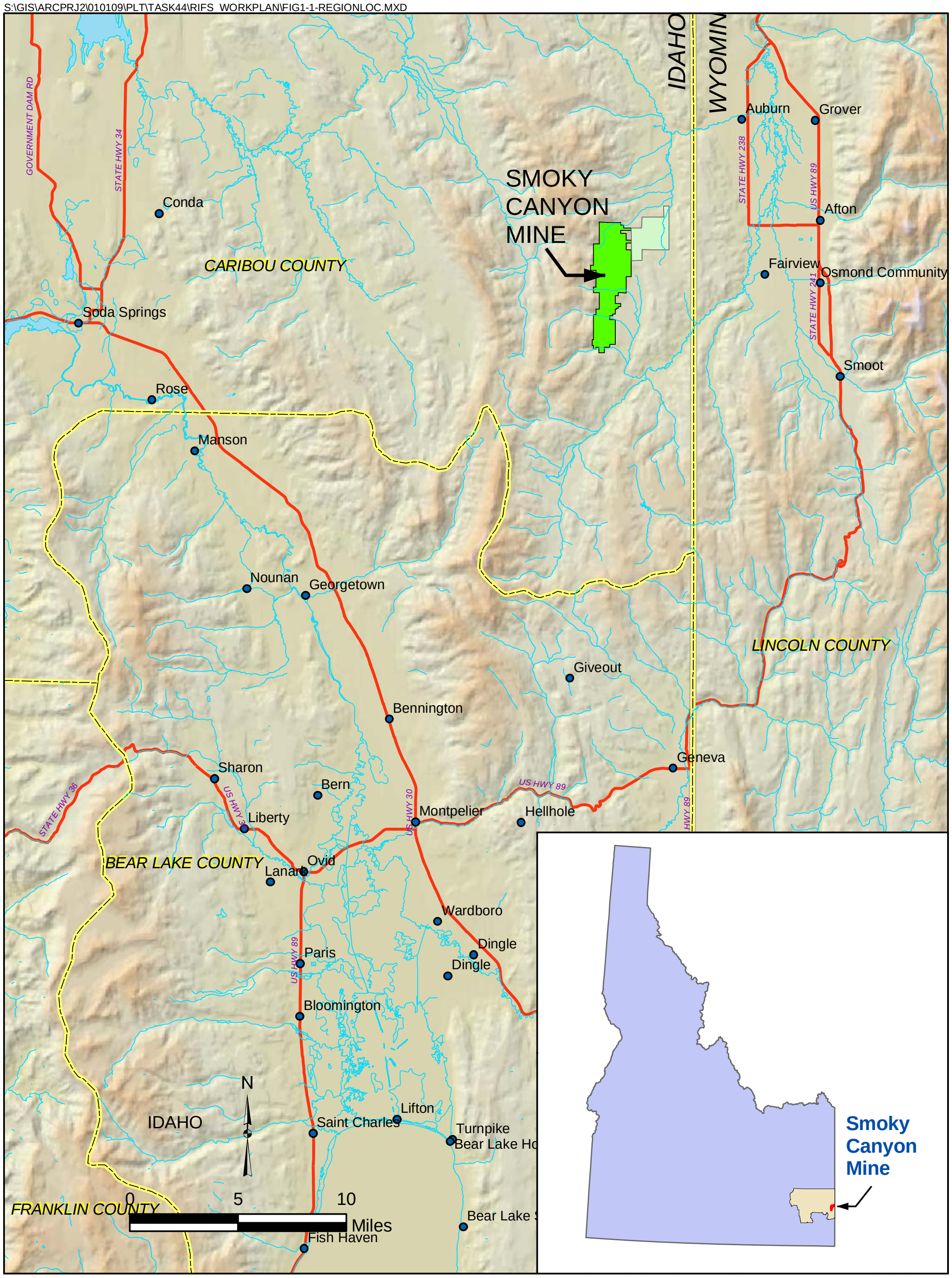

Figure 1-1: Smoky Canyon Site Location

At present, the selenium concentrations at Hoopes Spring, lower South Fork Sage Creek, and lower Sage Creek are above the Idaho surface water quality criterion for protection of aquatic life (0.005 mg/L = chronic criterion; IDAPA 58.01.02.210), and selenium concentrations at Hoopes Spring and lower South Fork Sage Creek Springs also exceed Idaho's current acute criterion (0.02 mg/L). The selenium mass load discharged at these two springs is the primary source of selenium to surface waters in the lower Sage Creek drainage.

Remedial actions, which may include water treatment, will be taken to reduce selenium concentrations in Hoopes Spring, South Fork Sage Creek, and lower Sage Creek. The target reductions in selenium concentrations will ultimately depend on final remedial action objectives established for this site (e.g., Idaho surface water quality criterion, a site-specific standard, etc.). Hoopes Spring represents a relatively low-selenium-concentration (i.e., < 0.08 mg/L), high-flow treatment candidate. South Fork Sage Creek springs discharge at numerous locations, some of which are relatively low-selenium (< 0.08 mg/L) and moderate- to low-flow (<40 gpm) treatment candidates. At both of these springs, treated water would be returned to surface water flow systems that support aquatic life. Reducing the selenium mass transport to Sage Creek via these springs is the highest priority for both Simplot and the USFS, because successful reduction of the selenium mass load associated with Hoopes Spring will provide the greatest improvement in surface water quality within the lower Sage Creek drainage.

Simplot prepared a Treatability Study Technical Memorandum (NewFields, 2009a) that identified a range of candidate technologies for treatment of water to remove selenium and recommended treatability studies to obtain additional information regarding their effectiveness, implementability, and cost prior to the FS. The technical memorandum identified technologies for further evaluation. One of those technologies was a semi-passive, chemically based, water treatment technology developed and marketed by Liberty. This treatment technology uses ZVI chemistry to remove selenium from the water and is referred to as the Liberty ZVI technology. As described in greater detail in the Treatability Study Technical Memorandum, there are limited field studies using the Liberty ZVI technology. One pilot study was being conducted in West Virginia where treated water was being discharged to a pond and then to a stream system that is a natural fish habitat. Very few data are available. For this reason, Simplot proposed a pilot study at Smoky Canyon Mine to further evaluate potential application of this technology for water treatment at the Mine.

Simplot submitted a work plan and sampling and analysis plan (SAP) for a pilot study of the Liberty ZVI technology to the USFS on September 17, 2009 (NewFields, 2009b). The work plan describes the pilot study design, the data quality objectives, and how the pilot study was to be implemented. The SAP describes the sample collection procedures, field measurement procedures, quality control and quality assurance, and related data review and documentation procedures.

The pilot study began operating on October 5, 2009 and operated until September 12, 2011.

1.2 Pilot Study Objectives

The purpose of this pilot study was to conduct a remedy-screening treatability test that could provide the additional data needed to support the development and evaluation of remedial alternatives as part of the FS. This pilot study provides data that can be used to evaluate and/or design “scaled-up” versions of the treatment system for full-scale applications, if appropriate.

The primary objective of this pilot study is to evaluate the site-specific effectiveness, implementability, and (if effective and implementable) the cost of the Liberty ZVI treatment technology for removing selenium from spring water at the Smoky Canyon Mine.

The work plan describes the pilot study objectives in greater detail (NewFields, 2009b).

1.3 Report Organization

The report is organized into the following sections:

- Section 2 presents an overview of the Liberty ZVI treatment technology.
- Section 3 describes the implementation and results of the Liberty ZVI pilot study conducted at the South Fork Sage Creek Springs adjacent to the Smoky Canyon Mine area.
- Section 4 is a summary of the findings and conclusions based on results from the pilot study.

2.0 OVERVIEW OF THE PILOT TREATMENT TECHNOLOGY

ZVI has been widely used in the removal of environmental contaminants from water. The Liberty ZVI Treatment System uses ZVI chemistry to remove selenium from water. Zhang et al. (2005) describe the selenium removal mechanisms for ZVI as follows:

1. Oxidation of solid iron releases iron (II) (ferrous) and iron (III) (ferric) ions:

   $2\ Fe^0(s) + O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4OH^-$

   $4\ Fe^{2+} + O_2 + 2H_2O \rightarrow 4Fe^{3+} + 4OH^-$

2. Formation of various ferrous and ferric hydroxides with free hydroxyl ions (OH^-):

   $Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$

3. Followed by further oxidation of ferrous hydroxides to ferric minerals, including ferrihydrite:

   $Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3$

4. Abiotic reduction of selenate (Se(VI)) to selenite (Se(IV)) and to elemental selenium (Se(0)), for example:

   $2\ SeO_4^{2-} + 4Fe(OH)_2 + 2H_2O \rightarrow 2SeO_3^{2-} + 4Fe(OH)_3$

   Elemental selenium is relatively insoluble and is removed from solution by precipitation. Selenite adsorbs onto the ferric/ferrous hydroxide mineral surfaces to a greater extent than selenate, and selenite is removed from solution by sorption processes.

According to Liberty, the technology is an enhancement over classical ZVI systems as it incorporates measures to significantly reduce treatment times in a system that can operate in remote locations where power is not provided (thought Liberty reported that power may be needed for some parts of the system to prevent freezing during harsh winter conditions). The system utilizes micro-scale ZVI that is permanently adhered to a sponge-like matrix providing a high porosity (i.e., >80 percent). The potential advantages of this system are the large surface area provided by the micro-scale ZVI and the reduced potential for problems related to ZVI compaction and loss of porosity over time. The ZVI treatment media is placed in a closed container, and influent water is fed into the treatment unit through gravity flow. As water flows through the media, selenium adsorbs to the iron or is precipitated as elemental selenium, and the water leaves the treatment container with a reduced selenium concentration. According to

Liberty, the sponge-like matrix eliminates scale and plugging issues typically associated with ZVI systems.

Information provided by Liberty prior to the pilot study implementation stated that the system has been proven effective in achieving selenium concentrations below 0.005 mg/L when treating water with initial concentrations as high as 3 mg/L selenium and over 1,300 mg/L total dissolved solids (TDS).

3.0 PILOT STUDY IMPLEMENTATION AND RESULTS

The Liberty pilot-scale treatment system was located directly downstream of the South Fork Sage Creek springs on the north side of the creek just upstream of a long-term sampling location within South Fork Sage Creek (LSS) (Figure 3-1). The pilot system was designed to treat a maximum of 24 gallons per minute (gpm).

3.1 Site Preparation and System Configuration

A trench was dug along the north side of the South Fork Sage Creek springs area to intercept spring water containing elevated selenium concentrations (Figure 3-2). The trench was lined with a geotextile fabric and a perforated pipe to collect all the spring water intercepted. The northern springs were initially thought to have a combined flow rate of 25 gpm (NewFields 2009b), but after construction of the pipeline, the flow rate from the northern springs was approximately 100 gpm. The intercepted water was directed by the pipe to a chamber where the majority of the spring water was returned to the creek while a portion flowed into a buried plastic pipe that fed the Liberty pilot system.

The treatment system was below the spring discharge elevation; allowing the pilot system to be gravity fed. The pipeline entered a small structure in which there was a shutoff valve, an influent flow totalizer, and a sample port. The pipeline exited the structure and entered a manifold system designed to feed water to the individual treatment units. The influent spring water was split to feed eight identical 'totes' containing the ZVI media in a parallel configuration (Figures 3-3 and 3-4). The totes and associated piping all sat on a level gravel pad. Each tote was approximately four feet wide by four feet deep by four feet tall, with a treatment capacity of 3 gpm, and a contact time between the water and ZVI media of 1 to 2 hours (depending on the porosity in each tote). Water flowed through a valve, a visual flow meter, downward through the media, and exited from the bottom of the tote. The water flowed up through a stand-pipe (designed to keep the media saturated) before entering a manifold that combined the effluent from all the totes. There was a sample port present just after the stand-pipe to facilitate sampling of the effluent from each individual tote.

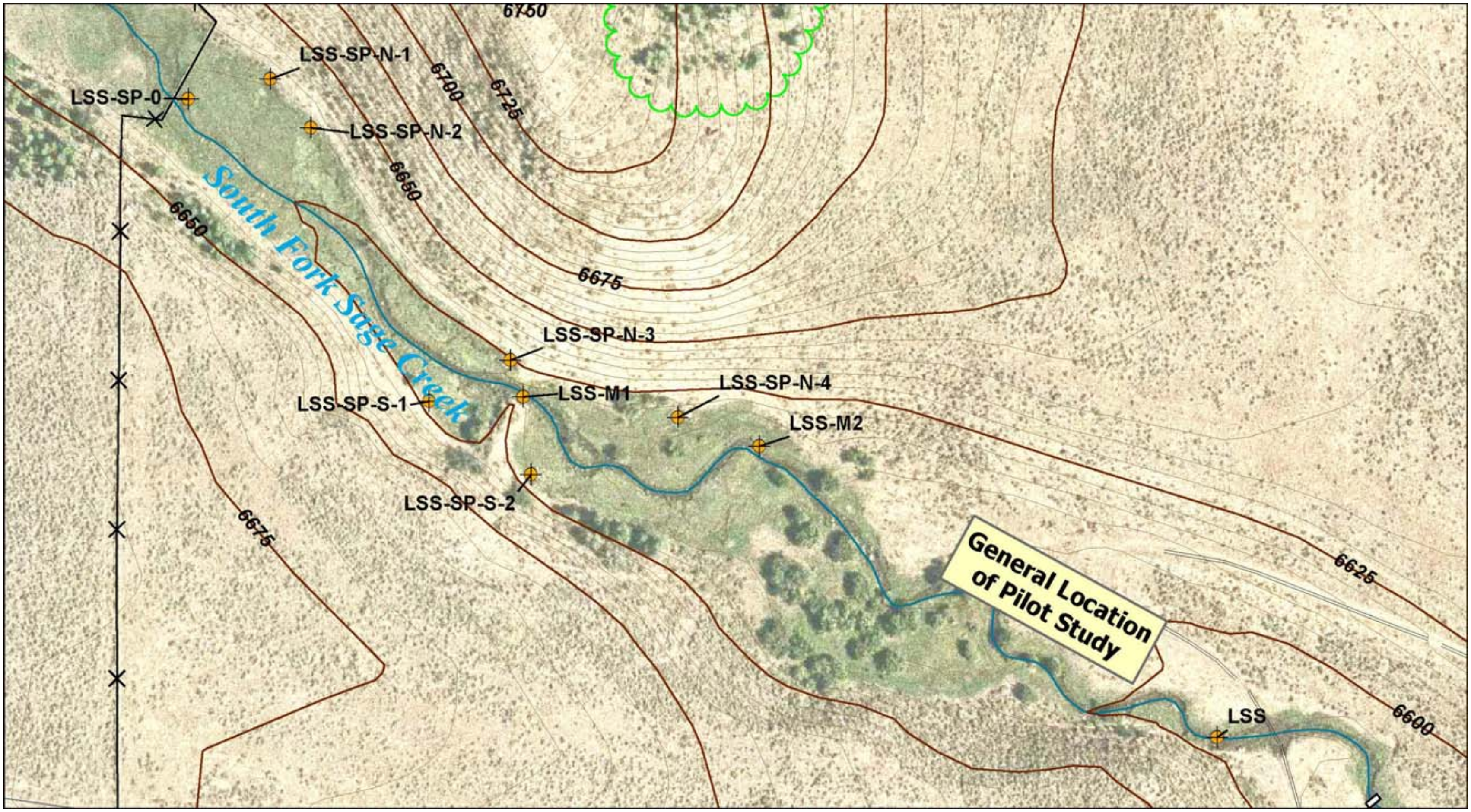

Figure 3-1: Location of Pilot Study Setup

Figure 3-2: Photo showing trench prior to lining and pipe installation.

Figure 3-3: Photo showing treatment system control structure, totes, and settling pond.

Figure 3-4: Photo showing tote piping manifold.

The treated effluent water from the ZVI system contained dissolved and particulate iron as well as reduced dissolved oxygen (DO) levels. Therefore, the pilot system included aeration step/settling pond prior to discharge to the creek. The combined effluent discharged into a concrete drop structure that began the re-aeration process (a detailed description is provided in Section 3.4). The water exiting out of the drop structure entered into the oxidation/settling pond (Figure 3-5). The pond capacity was approximately 25,000 gallons with a surface area of approximately 8,000 square feet. At the system's maximum flow rate (24 gpm), the residence time of effluent water in the pond was approximately 17 hours. The pond contained two concrete baffles to minimize the potential for 'short-circuiting'. The pond discharged to an open channel containing a series of small gravel-lined ponds before returning the treated effluent to South Fork Sage Creek. The channel was initially 50-100 feet long but was reconstructed in late-October/early-November 2009 so that it was approximately 150 feet long with additional pools to enhance aeration/iron removal (Figure 3-6).

Figure 3-5: Photo showing aeration/settlment pond.

Figure 3-6: Photo showing aeration channel.

3.2 System Monitoring

Monitoring of the Liberty pilot system included:

- Verifying there were no leaks in the system;
- Adjusting the metering valves to ensure that each treatment unit was receiving the correct flow rate;
- Measuring field parameters (pH, temperature, DO, etc) and collecting samples from the influent;
- Measuring field parameters and collecting samples from the combined effluent (and occasionally from the individual treatment unit effluent);
- Measuring field parameters and collecting samples from the oxidation/settling pond; and,
- Measuring field parameters and collecting samples from the discharge channel directly before it intersects to South Fork Sage Creek.

All monitoring and sampling results are discussed in Sections 3.4 through 3.6.

3.3 Laboratory Data Quality Evaluation

Samples collected during the pilot study were submitted to contracted laboratories for the analyses specified by the Pilot Study Work Plan and Sampling and Analysis Plan (NewFields, 2009b). All the data packages for the Pilot Study were complete and provided the necessary information to allow for verification of data accuracy and assess compliance with specifications for data quality. Data validation was conducted by Formation Environmental in accordance with EPA's National Functional Guidelines for Inorganics Data Validation (EPA, 2004), to the extent possible, to evaluate data quality in terms of the measurement performance criteria included in the Work Plan. Data validation resulted in the assignment of qualifiers to some of the laboratory results, and those qualifiers are shown on the data tables included with this report. Appendix A presents a complete listing of validated results from the pilot study along with any data validation qualifiers assigned.

No data were rejected by the validator, and all pilot study sample results are considered acceptable for use in the pilot study effectiveness evaluation.

3.4 Startup Phase

Prior to construction of the pilot-scale treatment system, water samples were collected from each of the springs in the area, and from long term monitoring locations downstream. Samples from LSS, LSS-SP-N3, LSS-SP-N4 and USS were collected on September 9, 2009 (the data for this event are provided in Appendix A).

The pilot-scale treatment system was assembled on site between September 10 and October 4, 2009. Table 3-1 presents the sequence of key events during the pilot-scale treatment system startup.

Table 3-1: Sequence of events during pilot-scale treatment system startup.

Date	Flow Rate (gpm)	Startup Event
10/5/2009	3	Begin operation of tote#1.
10/10/2009	3	Oxidation/Settling Pond completely filled with treated water, and water began to be discharged from the pond to South Fork Sage Creek.
10/13/2009	6	Tote #2 brought online.
10/19/2009	7	Tote #3 brought online at a reduced flow of 1 gpm.
10/22/2009	5	Flow through tote #2 decreased to 1 gpm due to low DO and high turbidity in discharged water.
10/21/2009 - 10/24/2009	5	Implemented minor adjustments to drop structure and reconstructed the discharge channel between the Oxidation/Settling Pond and South Fork Sage Creek to enhance aeration of treated water and raise DO content before water is returned to South Fork Sage Creek.
10/26/2009	6	Increased flow through tote #3 to 2 gpm.
10/29/2009	9	Inflows to totes #2 and #3 were increased to 3 gpm each.
10/29/2009	12	Tote #4 brought online.
Week of 11/2/2009	12	Added permeable fabric curtain across Oxidation/Settling Pond.
11/3/2009 - 11/11/2009	24	Totes #5 through #8 brought online. System operating at full design capacity.

The pilot test startup was implemented in a phased approach. One of the treatment units (Tote 1) was brought online on October 5 at a flow of 3 gpm. Before the treated effluent was discharged from the pond, daily samples of treated effluent were sent for analysis of selenium and other constituents listed in Table 3-3 of the work plan and SAP (NewFields, 2009b). Because the analytical results showed that the treated effluent met all applicable standards and after discussion with the USFS, the oxidation/settling pond was allowed to discharge to the creek through the open discharge channel on October 10, 2009. Daily monitoring and sampling continued until October 13, 2009 when the process of bringing additional treatment units on-line began. The units were brought on line one at a time to ensure that the treated effluent discharged back to the creek maintained a low turbidity (i.e., low TDS concentration) and a high DO concentration. Through consultation with the USFS, it was agreed upon that the maximum turbidity within the treated effluent discharged back to the creek would be 15 NTU and the minimum DO concentration would be 6 mg/L. If these limits were not met after bringing an additional treatment unit online, the total flow through the system was be reduced by 1 gpm every day until the limits were met. The startup phase continued through November 9, 2009. During this period various methods and equipment were tested during the transition period to enhance re-aeration of the water—to increase the DO concentration of the treated effluent—and to enhance the settling of iron particulates—to decrease the turbidity/total suspended solids (TSS) of the treated effluent.

Methods tested to enhance re-aeration included:

- bubbling air within the discharge stand pipe on the effluent from each treatment unit;
- bubbling air within the combined effluent discharge pipe;
- modifying how the effluent entered the drop structure; and
- modifying the discharge channel between the oxidation/settling pond and the creek.

The ‘bubbling air’ methods were effective and capable of increasing the DO content from less than 0.5 mg/L to greater than 5 mg/L; however, they all required power and the only power available at the pilot study location was a gasoline-powered generator/compressor or batteries. Both of these power sources required daily maintenance which proved to be the limitation of this option for the remote location.

Modifying how the effluent entered the drop structure and constructing a longer discharge channel were both identified as passive methods that required no power and infrequent maintenance. The water entering the drop structure was initially dropping onto a few rocks that created some splashing to aid in re-aeration (Figure 3-7.A). The first modification was to add an upside-down plastic bucket that created a thin sheet of water that enhanced the re-aeration (Figure 3-7.B). Ultimately, the bucket was turned right-side up and many holes were drilled through the side of the bucket for small streams of water to exit through (Figure 3-7.C).

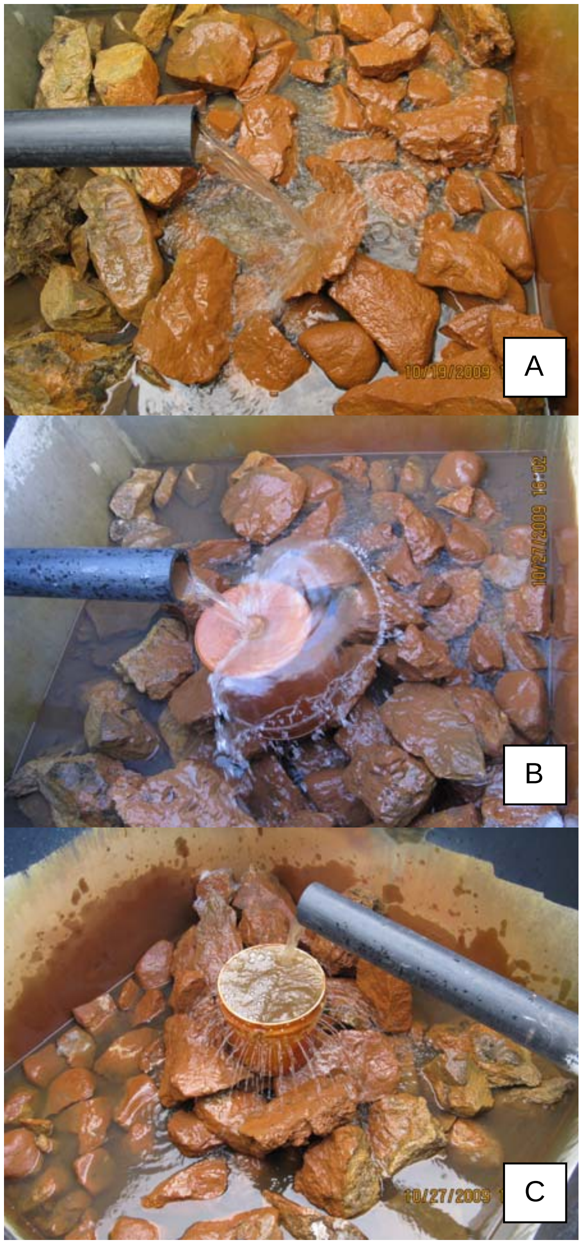

Figure 3-7: Drop structure modifications.

The discharge channel between the oxidation/settling pond and South Fork Sage Creek Springs was reconstructed in late-October to not only enhance re-aeration but to also enhance retention of the iron particulates. The initial discharge channel was approximately 75 feet long where the water discharged from the pond through a gravel bed and into a shallow pool before discharging to the creek. Over a period of a few days, the initial discharge channel was overwhelmed with iron particulate as additional treatment units were brought online. The reconstruction more than doubled the length of the discharge channel (see Figure 3-6).

Daily monitoring of field parameters was performed during the startup phase from October 5 through November 11, 2009 in accordance with the Pilot Study Work Plan (September 17, 2009) and revised Phase 1 monitoring schedule (memo dated October 8, 2009). Field parameter data are summarized in Table 3-2 below (the full data set is presented in Appendix A). For each monitoring location, the table shows the maximum, minimum, average, and total number of field parameter readings collected during startup. The table also contains the benchmark values for DO, pH and temperature. The table highlights benchmarks exceedances.

Table 3-2: Summary of pilot-scale treatment system startup field parameters.

Station	**Analyte Units**	**DO mg/L**	**Flow gpm**	**Fe, Total mg/L**	**ORP mV**	**pH su**	**Spec. Cond. uS/cm**	**Temp. C**	**Turbidity NTU**
	Benchmark	> 6				6.5 - 9.0		< 23	
Influent	Minimum	8.08	--	0	-90.6	7.43	257	9.47	0.3
	Maximum	9.86	--	0.1	372.1	7.85	388	10.33	1.93
	Average	8.78	--	0.05	48.5	7.67	372	9.97	0.84
	Number	30	--	5	28	30	30	30	30
Effluent-Tote 1	Minimum	0.05	2	2.78	-375	8.07	254	8.2	2
	Maximum	1.53	3	2.78	252.7	8.81	391	10.79	14.7
	Average	0.42	3	2.78	-254.2	8.47	364	10.00	7.97
	Number	30	30	1	29	29	29	30	25
Effluent-Tote 2	Minimum	1.34	1	--	-204.1	8.61	366	8.2	15.2
	Maximum	2.66	3	--	-187.2	8.64	368	9.45	44.9
	Average	2.09	2	--	-195.7	8.63	367	8.95	22.46
	Number	4	13	0	2	2	2	3	5
Effluent-Tote 3	Minimum	1.08	1	--	-198.5	8.98	335	8	7.66
	Maximum	1.56	2	--	-162.8	9.12	346	9.6	9.67
	Average	1.33	1	--	-180.7	9.05	341	8.86	8.77
	Number	4	7	0	2	2	2	3	3
Tote Effluent	Minimum	0.66	9	1.69	-250.9	8.15	347	9.12	3.58
	Maximum	1.36	24	1.69	-203.4	8.53	356	11.45	16.2
	Average	0.88	17	1.69	-227.3	8.36	352	10.47	12.96
	Number	8	8	1	8	8	8	8	8
Pond Inlet	Minimum	3.78	--	0.24	-142.7	7.89	250	4.75	10.1
	Maximum	5.79	--	0.24	1.1	8.31	382	12.15	53.8
	Average	4.89	--	0.24	-67.8	8.13	359	7.94	22.35
	Number	16	--	1	16	16	16	16	14
Pond	Minimum	2.55	--	0.06	-94.3	7.71	249	4.35	6.63
	Maximum	6.33	--	0.39	141.6	8.36	383	12.8	50.4
	Average	4.92	--	0.27	-29.8	8.07	354	7.30	16.42
	Number	31	--	4	30	26	31	31	28

Table 3-2: Summary of pilot-scale treatment system startup field parameters (Con't).

Station	Analyte Units	DO mg/L	Flow gpm	Fe, Total mg/L	ORP mV	pH su	Spec. Cond. uS/cm	Temp. C	Turbidity NTU
	Benchmark	> 6				6.5 - 9.0		< 23	
Pond Outlet	Minimum	4.14	--	0.05	-76.4	7.84	249	4.38	5.31
	Maximum	7.12	--	0.11	71.4	8.22	382	12.22	44
	Average	5.61	--	0.09	-19.9	8.08	353	7.78	12.73
	Number	16	--	3	16	16	16	16	14
Discharge	Minimum	4.18	--	0.03	-61.8	7.71	249	3.18	4.3
	Maximum	9.27	--	0.47	166.6	8.26	384	13.25	55.8
	Average	6.68	--	0.15	32.2	8.04	355	7.33	12.93
	Number	25	--	24	24	25	25	25	25

Notes:
No flows were collected for the influent, the pond inlet, the pond outlet or the discharge canal.
Grey shaded values indicate a parameter that was outside the benchmark range.
Field parameters were not collected individually for totes 4 through 8. The "Tote Effluent" sample location, measured the parameters from all 8 totes once they had been recombined, prior to leaving the system piping manifold.

As shown in table 3-2, there were exceedances for the pH benchmark within the system in the Tote 3 effluent; however, the pH was within the acceptable range at the discharge location for all samples. DO levels were consistently below the benchmark level for water within the treatment system and in the pond. Average DO in the discharge was over the benchmark, but the concentration did briefly fall below 6 mg/L on two occasions. Figure 3-8 shows DO concentrations for the four main monitoring locations over the course of the startup activities.

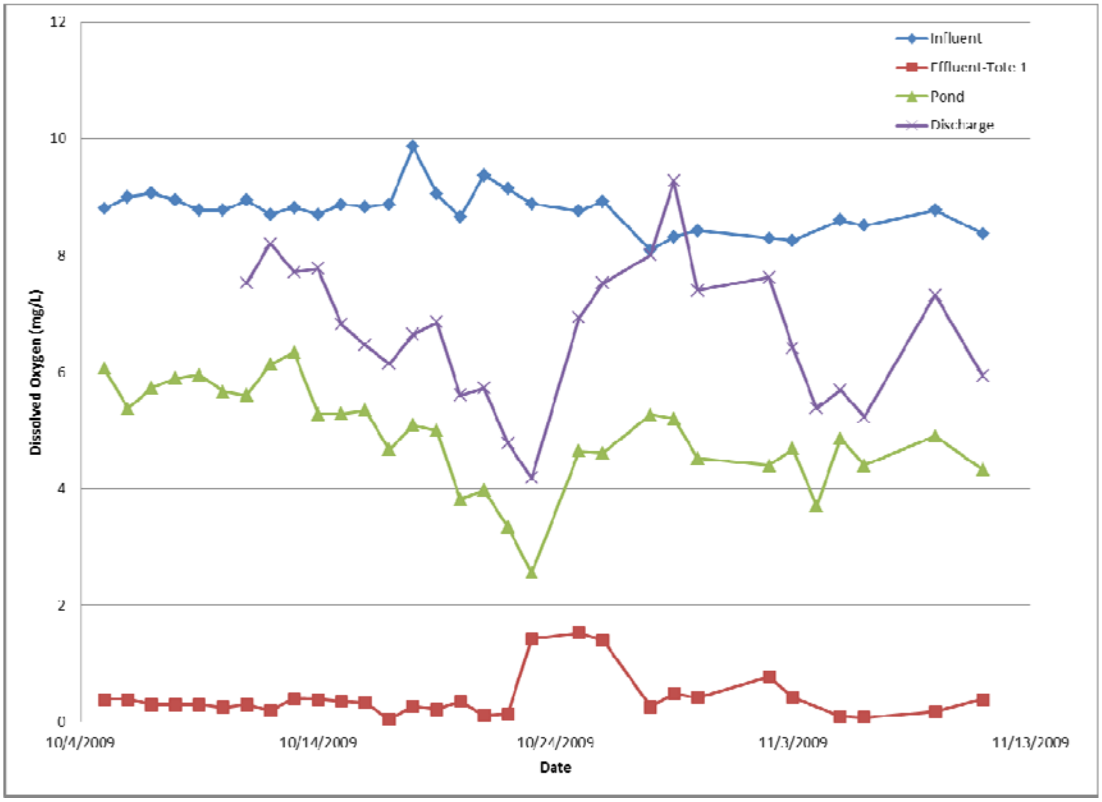

Figure 3-8: Dissolved oxygen concentrations observed during system startup.

As shown in Figure 3-8, DO levels in the influent ranged between 8 and 10 mg/L. After the water passed through the treatment tote, the DO concentration was reduced to below 2 mg/L. The DO increased as the water left the treatment system, entered the pond, flowed through the aeration channel, and was eventually discharged back to the creek.

Samples for laboratory analysis were collected from system monitoring locations including: the influent, the treated tote effluent, water from the aeration pond, and at the final discharge to South Fork Sage Creek. All samples were collected in accordance with Pilot Study Work Plan and revised monitoring schedule (October 8, 2009) with submittal of samples for laboratory analyses as specified in the Pilot Study Work Plan. Table 3-3 presents a summary of selenium results from startup and the percent reductions observed in selenium concentrations.

Table 3-3: Summary of selenium concentrations (mg/L) during pilot system startup.

Date >>	10/5/2009		10/7/2009		10/18/2009	
Fraction >>	Dissolved	Total	Dissolved	Total	Dissolved	Total
Influent	0.033	0.0323	0.0324	0.0343	0.0308	0.0321
Effluent-Tote 1	0.0241	0.0246	0.0238	0.0243	0.0223	0.0214
Percent Removal (vs. Influent)	27.0%	23.8%	26.5%	29.2%	27.6%	33.3%
Pond[a]	0.0189	0.0189	0.0216	0.022	0.0213	0.0213
Percent Removal (vs. Influent)	42.7%	41.5%	33.3%	35.9%	30.8%	33.6%
Percent Removal (vs. Tote Effluent)	21.6%	23.2%	9.2%	9.5%	4.5%	0.5%
Discharge	--	--	--	--	0.0208	0.0202
Percent Removal (vs. Influent)	--	--	--	--	32.5%	37.1%
Percent Removal (vs. Pond)	--	--	--	--	2.3%	5.2%

Note:
a - Pond filled with treated water, and discharge from the pond to South Fork Sage Creek began on October 11, 2009.
Grey shaded cells indicate a concentration exceeding the surface water benchmark level of 0.005 mg/L selenium.
Laboratory samples only collected after Tote-1 during startup.
No laboratory or validation qualifiers presented in this table. All concentrations reported were above the method detection level.

As shown in Table 3-3, some selenium removal (up to 33.3% percent) occurred within the treatment totes. Some additional selenium removal also appeared to be occurring in the pond. Full analytical data for the system startup are presented in Appendix A. Figure 3-9 shows the total selenium concentrations observed at the monitoring locations in comparison to the average influent concentration. The discharge to the creek was monitored daily during startup and there were significantly more analytical data for that location.

Figure 3-9: Total selenium concentrations during system startup.

As show in Figure 3-9, total selenium concentrations were reduced between the influent and the discharge; however, the benchmark level of 0.005 mg/L was exceeded by all samples collected during startup. The average selenium removal was in the range of 40%.

3.5 First Operating Phase

This section describes system performance during the period of time from November 9 to March 2 (the first operating phase).

The treatment system operated at its full capacity of 24 gpm from November 9, 2009, through March 1, 2010, with a brief period of slightly reduced inflow due to obstruction of flow to one of the eight totes in mid-February. As a result of the lower flow rate, that tote froze and was no longer open to inflow or outflow of water. Flow to that tote was restored once the inlet line was cleared and the tote thawed by February 23. The system was operating at full capacity again by March 1. Samples were collected on March 2, and the system was shut down.

Table 3-4 presents the summary of field parameters observed during the first operating phase. As expected, the DO concentration reduced significantly in the totes. Concentrations were increased in the drop structure/aeration pond, and with the exception of one sample, all discharge samples were above the DO benchmark. The treatment system slightly increased the water pH (average influent 7.79 s.u. compared to average discharge of 8.36 s.u.). The system did not significantly affect the specific conductance. Turbidity was increased in the totes and generally reduced by the discharge point. Water temperatures around 9.5°C in the influent dropped to 3.7°C in the discharge, cooled by the low winter temperatures.

Table 3-4: Summary of field parameters observed during the first operating phase.

Station	Analyte Units	DO mg/L	Flow gpm	Fe, Total mg/L	ORP mV	pH su	Spec. Cond. uS/cm	Temp °C	Turbidity NTU
	Benchmark	> 6				6.5 - 9.0		< 23	
Influent	Minimum	7.97	--	--	-62.7	7.71	368	9.23	0.47
	Maximum	9.7	--	--	48.9	7.85	380	9.89	0.74
	Average	8.93	--	--	6.85	7.79	375.2	9.49	0.58
	Number	5	0	0	4	5	5	5	3
Tote Effluent	Minimum	1.36	21	--	-265.5	8.15	308	8.11	6.37
	Maximum	2.66	24	--	-199.7	8.54	357	10.14	14.1
	Average	1.8	23.5	--	-221.63	8.34	337.33	8.86	10.57
	Number	6	6	0	6	6	6	6	4
Pond	Minimum	4.33	--	--	-143.3	8.12	322	4.34	10.5
	Maximum	8.53	--	--	-2.4	8.4	355	7.69	37.4
	Average	6.53	--	--	-77.75	8.25	341.29	6.50	20.95
	Number	7	0	0	6	7	7	7	4
Discharge	Minimum	5.93	--	0.07	-15.9	8.2	312	2.15	3.2
	Maximum	14.43	--	0.11	158.6	8.54	349	6.13	18.4
	Average	10.95	--	0.09	116.42	8.36	339.57	3.71	8.54
	Number	7	0	4	6	7	7	7	6

Notes:
No flows were collected for the influent, the pond inlet, the pond outlet or the discharge canal.
Grey shaded values indicate a parameter that was outside the benchmark range.

Cold weather during the winter months caused the continuous field measurement equipment to malfunction. The results presented in Table 3-4 were recorded from hand held units used at the time of sample collection for laboratory analysis.

Selenium removal improved from startup during the first operational phase. In February 2010, the system removed close to 85% of the selenium from the influent. However, with the exception of the February dissolved selenium, concentrations in the discharge were still over the surface water benchmark of 0.005 mg/L. Table 3-5 summarizes total and dissolved selenium concentrations and system selenium removal performance during the first operating phase.

Table 3-5: Summary of selenium concentrations (mg/L) during the first operating phase.

Date >>	11/22/2009		12/8/2009		12/16/2009		1/11/2010		2/10/2010		3/2/2010	
Fraction >>	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Influent	0.0346	0.0343	0.0352	0.0348	0.0319	0.0313	0.0343	0.034	0.0313	0.0315	0.0374	0.0363
Tote Effluent	0.0174	0.0171	0.0163	0.0162	0.0102	0.0104	0.0154	0.016	0.004	0.0045	0.0102	0.0107
Percent Removal (vs. Influent)	49.7%	50.1%	53.7%	53.4%	68.0%	66.8%	55.1%	52.9%	87.2%	85.7%	72.7%	70.5%
Pond	0.0166	0.0169	0.0168	0.0169	0.0104	0.0106	0.016	0.016	0.0047	0.0054	0.008	0.0086
Percent Removal (vs. Influent)	52.0%	50.7%	52.3%	51.4%	67.4%	66.1%	53.4%	53.8%	85.0%	82.9%	78.6%	76.3%
Percent Removal (vs. Tote Effluent)	4.6%	1.2%	-3.1%	-4.3%	-2.0%	-1.9%	-3.9%	1.9%	-17.5%	-20.0%	21.6%	19.6%
Discharge	0.0141	0.0153	0.0165	0.0164	0.0094	0.0107	0.015	0.016	0.005	0.0053	0.0086	0.0087
Percent Removal (vs. Influent)	59.2%	55.4%	53.1%	52.9%	70.5%	65.8%	56.3%	53.2%	84.0%	83.2%	77.0%	76.0%
Percent Removal (vs. Pond)	15.1%	9.5%	1.8%	3.0%	9.6%	-0.9%	6.3%	-1.3%	-6.4%	1.9%	-7.5%	-1.2%

Note:
Grey shaded cells indicate a concentration exceeding the surface water benchmark level of 0.005 mg/L selenium.
No laboratory or validation qualifiers presented in this table. All concentrations reported were above the method detection level.

As expected, the majority of the selenium removal occurred within the treatment totes. Selenium removal downstream of the totes (in the aeration/settling pond) was minimal. The average selenium removal achieved by the entire pilot system averaged 65% over this period, with a maximum removal at 83%. The higher treatment efficiency appeared to be associated with lower flow (as the flow controllers became clogged; see below) and therefore higher residence time. Although selenium removal increased, iron precipitation/staining significantly increased at this time. Total selenium concentrations exceeded the 0.005 mg/L benchmark in all samples collected.

The major maintenance issues with the pilot study were plugging of the metering valves and plugging of the flow meters. The metering valves would become plugged with invertebrates or debris that had been flushed through the system. The plug could be easily fixed by opening the metering valve and then restoring the flow rate to 3 gpm. However, it was a recurring problem that was not resolved during the pilot study. During nearly each visit by the operators to the pilot, there was at least one treatment unit that was not receiving 3 gpm due to a plugged metering valve. The flow meters became plugged over time due to algae growth. The flow meters are clear which allowed the algae to grow and ultimately reduce the flow to each treatment unit considerably. All of the flow meters required routine disassembly and cleaning to maintain the design flow of 3 gpm.

The heat of the water flowing through the system was sufficient to keep the pipes and the treatment units from freezing during the cold winter months. One of the treatment units froze in mid-February due to insufficient flow caused by a plugged metering valve/flow meter. Although ice formed on the edges of the drop structure, the piping in and out of the drop structure remained free of ice. The oxidation/settling pond and the pools within the discharge channel were mostly covered with ice during the winter months, but the ice cover did not seem to adversely affect the re-aeration rate.

On February 23, Simplot personnel noted additional accumulation of oxidized iron precipitates along the gravel-lined floor of the channel carrying treated water from the settling pond to South Fork Sage Creek. Although the iron concentrations reported for the February 10 sample of treated water entering South Fork Sage Creek indicated lower total and dissolved iron concentrations than previously reported for the system effluent, Simplot decided to shut down the pilot system operations on March 2, 2010 to avoid any transport of the distinctively orange-colored precipitates into the active stream channel for South Fork Sage Creek.

3.6 Second Operating Phase

On June 21 Simplot completed construction of a sand filter between the treatment pond and the aeration channel (Figures 3-10 and 3-11). The treatment system was brought back online and reached full treatment capacity (24 gpm) on June 23, 2010. The treatment system was run at full capacity from June 23, 2010 to August 3, 2011. The purpose of the second operating phase was to observe how the system performed over a longer period of time, including warmer summer months and a full winter. This section summarizes the performance of the system for the second operating phase.

Figure 3-10: Photo showing installation of buried plastic pipe manifold for sand filter

Figure 3-11: Photo showing sand filter.

Table 3-6 summarizes the field parameters from the second operating phase. When the treatment units were brought back online, field parameters were monitored every fifteen minutes at the discharge to the drop structure (i.e., combined treatment unit discharge). The restart procedure took approximately eight hours. In addition, field measurements were completed daily during the first week following restart (June 23-June 30, 2010). After the initial restart, field parameters were collected less frequently than during the first operating phase. Due to the monitoring schedule, the values presented in the summary table are slightly skewed toward the performance of the system during the restart period.

Table 3-6: Summary of field parameters observed during the second operating phase

Station	Analyte Units	DO mg/L	Flow gpm	Fe, Total mg/L	ORP mV	pH su	Spec. Cond. uS/cm	Temp C	Turbidity NTU
	Benchmark	> 6				6.5 - 9.0		< 23	
Influent	Minimum	6.74	--	0	-50.8	7.25	337	9.8	0.44
	Maximum	10.82	--	0	62.5	7.99	491	10.69	1.82
	Average	8.98	--	0	-14.09	7.80	383.23	10.31	0.99
	Number	13	0	4	12	13	13	13	12
Tote Effluent	Minimum	1.72	3	0	-263.1	7.21	132	9.42	1.11
	Maximum	9.01	24	3.3	-52.7	9.5	479	13.48	31.6
	Average	2.89	17.91	1.56	-201.91	8.76	262.81	11.518	5.40
	Number	37	32	12	37	37	37	37	35
Pond	Minimum	5.17	--	0.02	-118.9	7.32	274	10.18	4.69
	Maximum	12.09	--	0.27	55.4	8.69	472	14.54	23.7
	Average	7.42	--	0.13	-48.77	8.11	363.25	12.18	15.64
	Number	12	0	8	12	12	12	12	12
Discharge	Minimum	8.07	--	0	-64.9	7.41	258	9.26	0.61
	Maximum	14.53	--	0.09	168.1	8.64	464	19.12	4.2
	Average	9.24	--	0.037	5.95	8.22	356.31	14.60	1.79
	Number	13	0	12	13	13	13	13	13

Notes:
No flows were collected for the influent, the pond inlet, the pond outlet or the discharge canal.
Grey shaded values indicate a parameter that was outside the benchmark range.

DO showed similar trends to startup and the first operating phase; however, the concentrations were consistently over 6 mg/L in the discharge for the entire second operating phase. All of the other parameters in the discharge also met the surface water benchmark levels.

When the system was restarted on June 23, 2010, the sand filter was not capable of passing all 24 gpm due to air pockets within the sand. Approximately 2 gpm (8% of total flow) was bypassing the sand filter. By June 26, 2010, the air pockets had been purged from the media and all 24 gpm was passing through the sand filter. On July 7, 2010, the sand filter had begun to show signs of plugging with approximately 2 gpm bypassing the filter. On July 13, 2010, the bypass flow rate had increased to 6 gpm. After monitoring the treatment system, the flow to the treatment units was temporarily shut off and the upper few inches of the sand filter was scraped to remove accumulated iron particulate. When the flow was restored to the treatment units, all of the water passed through the sand filter. This cleaning process was repeated periodically throughout the rest of the pilot study.

Table 3-7 summarizes the selenium concentrations and the percent removal observed between June 2010 and September 2011. The influent/effluent selenium concentrations and associated percent removal are shown on Figures 3-12 and 3-13. As shown, influent and effluent concentrations increased during the second operational phase. All effluent selenium concentrations were above the 0.005 mg/L benchmark. The percent selenium removal was initially in the range of that achieved previously but quickly reduced as the treatment media became exhausted.

Table 3-7: Summary of selenium concentrations (mg/L) during the second operating phase, and system percent removal.

Date >>	6/24/2010		7/1/2010		8/10/2010		9/8/2010		10/18/2010		12/1/2010		2/9/2011		4/26/2011		9/12/2011	
Fraction >>	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**
Influent	0.0423	0.0427	0.0409	0.0416	0.0437	0.0443	0.0443	0.0432	0.0435	0.0446	0.0473	0.0503	0.0447	0.0482	0.0528	0.0543	0.0599	0.0598
Tote Effluent	0.0294	0.0309	0.0309	0.0309	0.0292	0.0314	0.0333	0.035	0.0368	0.0383	0.0289	0.029	0.0323	0.0328	0.0457	0.0465	0.0537	0.0548
Percent Removal (vs. Influent)	30.5%	27.6%	24.4%	25.7%	33.2%	29.1%	24.8%	19.0%	15.4%	14.1%	38.9%	42.3%	27.7%	32.0%	13.4%	14.4%	10.4%	8.4%
Pond	0.0191	0.0195	0.0299	0.031	0.0199	0.0229	0.0236	0.0248	0.0255	0.028	--	--	--	--	0.0486	0.0501	0.0579	0.0588
Percent Removal (vs. Influent)	54.8%	54.3%	26.9%	25.5%	54.5%	48.3%	46.7%	42.6%	41.4%	37.2%	--	--	--	--	8.0%	7.7%	3.3%	1.7%
Percent Removal (vs. Tote Effluent)	35.0%	36.9%	3.2%	-0.3%	31.8%	27.1%	29.1%	29.1%	30.7%	26.9%	--	--	--	--	-6.3%	-7.7%	-7.8%	-7.3%
Discharge	0.0161	0.0189	0.0277	0.0286	0.0192	0.0205	0.0256	0.0261	0.0272	0.0275	0.0407	0.0413	0.0398	0.0415	0.0453	0.0458	0.057	0.0576
Percent Removal (vs. Influent)	61.9%	55.7%	32.3%	31.3%	56.1%	53.7%	42.2%	39.6%	37.5%	38.3%	14.0%	17.9%	11.0%	13.9%	14.2%	15.7%	4.8%	3.7%
Percent Removal (vs. Pond)	15.7%	3.1%	7.4%	7.7%	3.5%	10.5%	-8.5%	-5.2%	-6.7%	1.8%	--	--	--	--	6.8%	8.6%	1.6%	2.0%

Note:
Grey shaded cells indicate a concentration exceeding the surface water benchmark level of 0.005 mg/L selenium.
No laboratory or validation qualifiers presented in this table. All concentrations reported were above the method detection level.

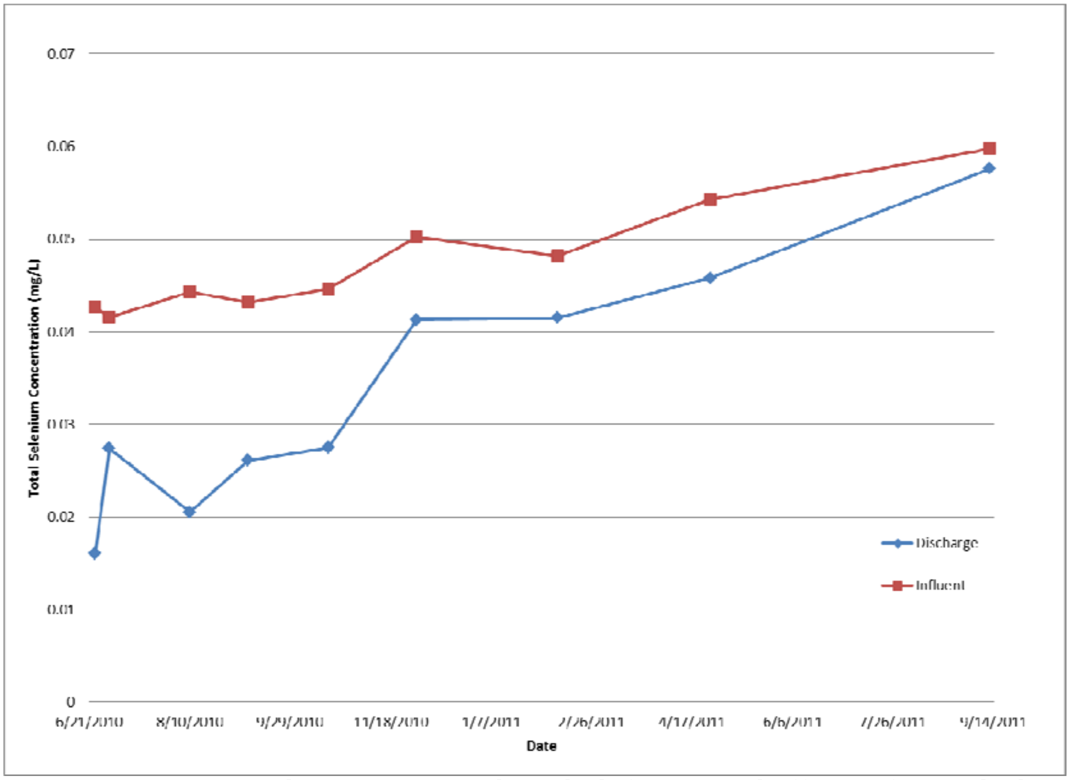

Figure 3-12: Total selenium concentrations in influent and effluent flows during the second operating phase.

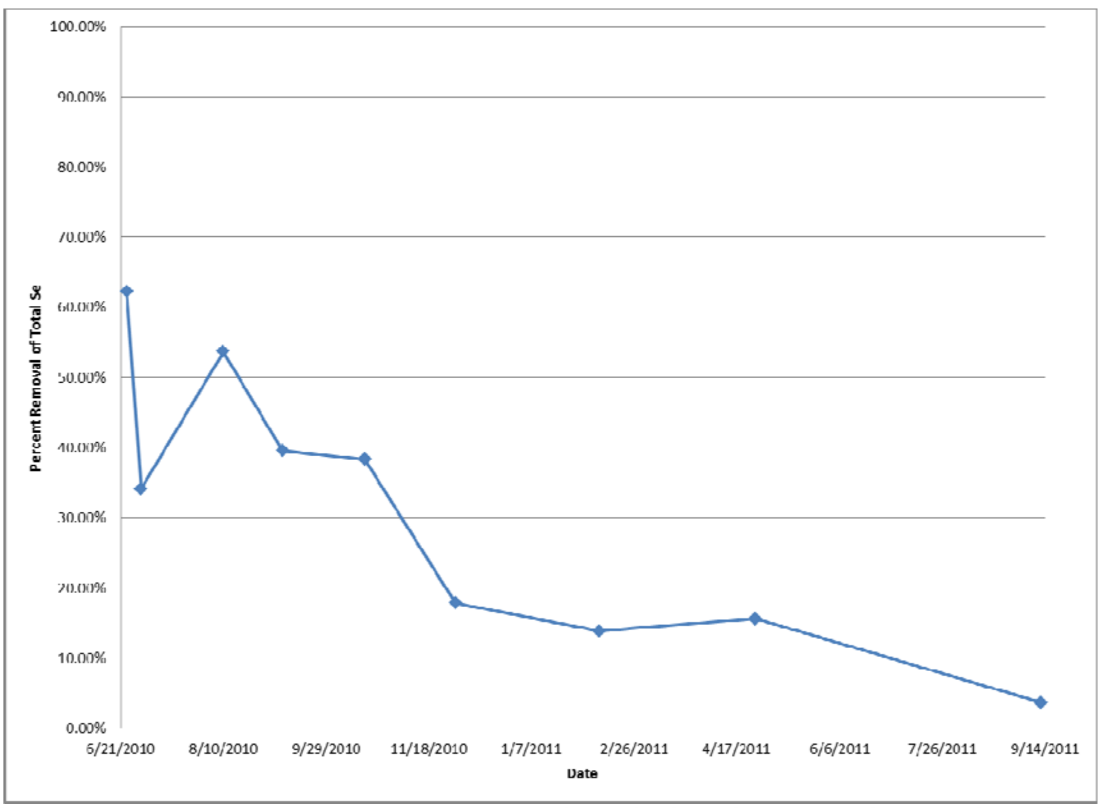

Figure 3-13 Percent removal of total selenium during the second operating phase.

3.7 Assessment of Treatment Byproducts

On April 10, 2012 two samples of the ZVI treatment media were collected from two different totes. The samples were analyzed using the toxicity characteristic leaching procedure (TCLP). The results from this analysis are presented in Table 3 8.

Table 3-8: TCLP results for used ZVI treatment media, Dissolved (mg/L Extract)

Sample Date		4/10/2012	
Location		Liberty Media 1	Liberty Media 2
Analyte	**TCLP Limit**		
Arsenic	5	0.05 U	0.05 U
Barium	100	0.54	0.7
Cadmium	1	0.05 U	0.05 U
Chromium	5	0.05 U	0.05 U
Lead	5	0.05 U	0.05 U
Mercury	0.2	0.01 U	0.01 U
Selenium	1	0.05 U	0.05 U
Silver	NA	0.05 U	0.05 U

Notes:

U = Not detected at or above the MDL

As shown in Table 3-8, all concentrations were significantly below their respective TCLP limit. Therefore it is concluded that spent treatment media would not be classified as hazardous waste.

4.0 SUMMARY AND CONCLUSIONS

This report described the implementation and results of a water treatment pilot study conducted by Simplot using a ZVI treatment process developed by Liberty. The study was performed at the Smoky Canyon Mine from October 5, 2009 to September 12, 2011.

ZVI has been widely used in the removal of environmental contaminants from water. According to Liberty, their technology was an enhancement over classical ZVI systems as it incorporated measures to significantly reduce treatment times in a system that can operate in remote locations where power is not provided. The system utilizes micro-scale ZVI that is permanently adhered to a sponge-like matrix providing a high porosity. The ZVI treatment media is placed in a closed container, and influent water is fed into the treatment unit through gravity flow. As water flows through the media, selenium adsorbs to the iron or is precipitated as elemental selenium, and the water leaves the treatment container with a reduced selenium concentration. According to Liberty, the sponge-like matrix eliminates scale and plugging issues typically associated with ZVI systems.

Overall the pilot study demonstrated that the Liberty process is not effective for removal of selenium at South Fork Sage Creek Springs. The system operated at the design conditions for the duration of the pilot study, however selenium removal was not sufficient to achieve the Idaho surface water quality criterion for protection of aquatic life (0.005 mg/L = chronic criterion; IDAPA 58.01.02.210) at any time during the test (Figure 4-1). Further the treatment effectiveness dropped off sharply after just 5 months of operation, as the ZVI media became exhausted (Figure 4-2).

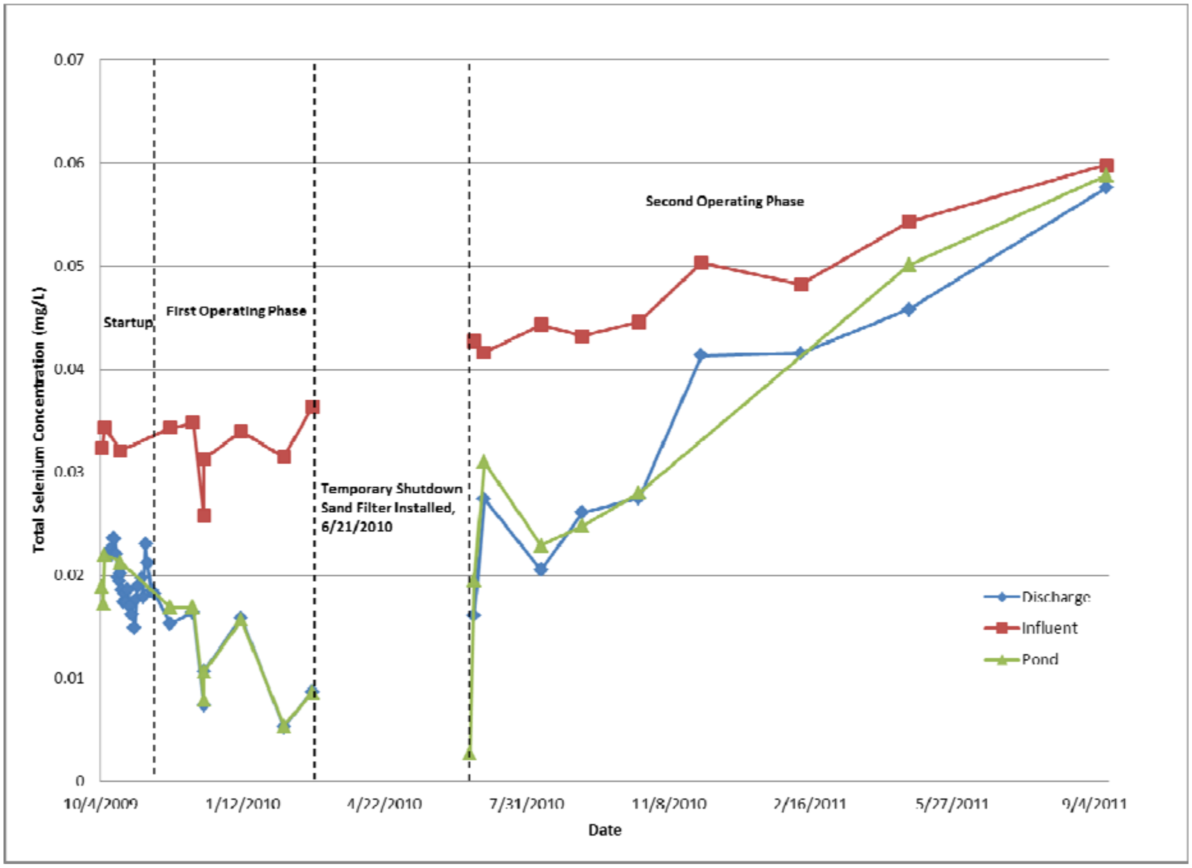

Figure 4-1: Pilot study overall system performance – total selenium concentration (mg/L).

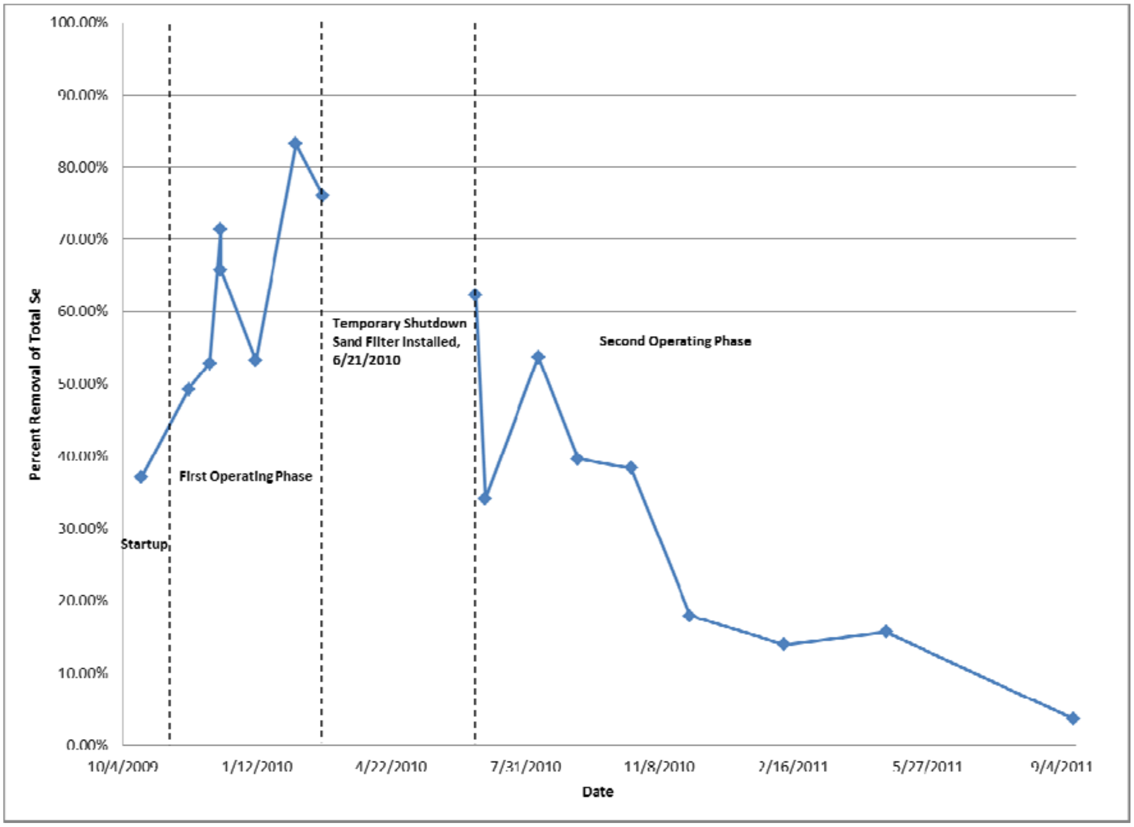

Figure 4-2: Pilot study overall system performance – selenium removal.

Operational difficulties were encountered with plugging of the metering valves and plugging of the flow meters. The metering valves would become plugged with invertebrates or debris that had been flushed through the system. The plug could be easily fixed by opening the metering valve and then restoring the flow rate to 3 gpm. However, it was a recurring problem that was not resolved during the pilot study. During nearly each visit by the operators to the pilot, there was at least one treatment unit that was not receiving 3 gpm due to a plugged metering valve. The flow meters became plugged over time due to algae growth. The flow meters are clear which allowed the algae to grow and ultimately reduce the flow to each treatment unit considerably. All of the flow meters required routine disassembly and cleaning to maintain the design flow of 3 gpm. In addition, there were significant issues with systems needed after the ZVI treatment to add DO and remove iron prior to discharge. Passive approaches to add DO were successful, however, the associated iron precipitation quickly overwhelmed the settling pond/sand filter. Overall these issues would require more significant operation and maintenance activities which would be difficult, given the remote setting and harsh winter conditions.

Based on the pilot study the Liberty ZVI technology is not considered a viable water treatment option to be considered in the FS.

5.0 REFERENCES

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APPENDIX A
Project Analytical Data
(On Disc)